VARIATIONS IN RESPIRATORY ACTIVITY IN RELATION TO SUNLIGHT

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(WITH TEN FIGURES)

Although the importance of light as a physiological stimulus and as a climatological factor has long been recognized, the complexity and multiplicity of biological light reactions has but recently been realized. As a working hypothesis, I have endeavored to analyze the light reactions by dividing them into two classes: (1) those reactions which are brought about by the light directly inducing chemical or physical changes of certain physiologically important substances *within the organism;* and (2) those reactions which are caused by the light affecting the *environment of the organism.* In the first class fall such reactions as the reduction of the acidity of the plant juices[1] with the consequent effects on growth, the inversion of disaccharides, and a number of other purely photochemical reactions. This paper is a prefatory announcement of a reaction which I believe to belong to the second class. It is my hope, by means of such an analysis, eventually to be able to interpret climatological light reactions upon a sound physiological basis.

As one of the most simply measurable plant activities, I have chosen respiration, as indicated by the evolution of carbon dioxide. The great complexity of the chemistry of this process in no wise affects the results for the present purpose.

The effect of light upon the respiratory activity of living things in general has received considerable attention. Unfortunately, however, in most of these investigations the source and nature of the light used were not considered, and hence we have a mass of uncoordinated and often contradictory results. In 1855 MOLESCHOTT[2]

[1] RICHARDS, H. M., Reports in Yearbook Carnegie Inst. Wash. 1913 and 1914. SPOEHR, H. A., Photochemische Vorgänge bei der diurnalen Entsäurung der Succulenten. Biochem. Zeitschr. **57**:95–111. 1913.

[2] MOLESCHOTT, JAC., Die internationale Sanitäts Konferenz in Rom. Wiener Med. Wochenschr. 1855. nos. 36–38.

noticed the increased carbon dioxide production of the frog under the influence of light, and later the same fact was observed in man by PETTENKOFER and VOIT[3] and others. However, in the higher animals the results become complicated by the action of the light on the nervous system.[4] The experiments on plants have been made mostly with fungi, but on account of the confusing influences of temperature, nutrient media, and sources of light, no definite conclusions can be drawn from these investigations.[5]

Recently, MEYER and DELEANO[6] have found that the carbon dioxide production of leaves at practically constant temperature and in the dark is decidedly higher during the daytime than at night. These workers consider the cause of this variation as lying within the organism. They say:

> Nachdem wir wissen, dass die Aufpraegung einer intermittiernden chronometrischen Bewegungsstruktur, welche zur periodischen Erhoehung der Kohlensaeureproduktion fuehrt, moeglich ist, duerfen wir wohl die Hypothese aufstellen, dass die regelmaessigen Schwankungen der Kohlensaeureproduktion an Stunden des Volltages bei normalen Laubblaettern nur durch den waehrend des Volltages stattfindenden Wechsel der Assimilationsintensitaet und wahrscheinlich erst waehrend ihres individuellen Lebens des Laubblattes hervorgerufen ist.

In the following experiments (mostly with wheat seedlings), the carbon dioxide production in the dark at constant conditions of temperature and humidity was measured by drawing air from out-of-doors over the plants, and then through a standard barium hydroxide solution. It was found that the rate at which carbon dioxide was produced during the hours of daytime was regularly higher than that produced during the night. It is evident that under these experimental conditions the only variable external

[3] PETTENKOFER, M., and VOIT, C., Über Kohlensäureausscheidung und Sauerstoffaufnahme während des Wachens und Schlafens beim gesunden u. kranken Menschen. Sitzber. Akad. Wiss. München **2**:236. 1866.

[4] NEUBERG, C., Beziehungen des Lebens zum Licht. Berlin. 1913 (p. 7).

[5] KOLWITZ, R., Über den Einfluss des Lichtes auf die Athmung der niederen Pilze. Jahrb. Wiss. Bot. **33**:128. 1899.

MAXIMOW, N. A. *Ibid.* Bot. Centralbl. **90**:94. 1902.

[6] MEYER, A., and DELEANO, N. T., Die periodischen Tag- und Nachtschwankungen der Atmungsgroesse im Dunkeln befindlicher Laubblätter und deren vermutliche Bezeihung zur Kohlensäureassimilation. Zeitschr. Bot. **3**:658–701. 1911; **5**:209–320. 1913.

condition to which the plants were exposed was the air of the daytime on the one hand, and that of the night on the other. Are there then any differences in the atmospheric air during day and night which might account for this remarkable variation in the respiratory activity? The first thing to suggest itself is the possible influence of the sunlight on the atmosphere.

The intensity of the violet and ultra-violet rays of the sunlight, as measured at the Desert Laboratory during 18 months, compared with the values generally given for atmospheric ionization, showed a remarkable similarity. DEMBER[7] and others[8] have reported the same fact from observations in other localities. Physicists are not agreed as to the exact relation between sunlight and atmospheric ionization,[9] nor is a discussion of this subject necessary for the present purpose. Suffice it to note that according to the observations of ELSTER and GEITEL, A. GOCKEL, VON SCHWEIDLER, and others, atmospheric ionization exhibits a main maximum about noon, a secondary maximum a little before sunrise, with minima after sunset and before sunrise. These values are subject to certain variations, since the ionization is affected by other meteorological factors, as is mentioned below.

In general, then, the highest respiratory activity takes place during the period of increased ionization. If the respiratory activity and atmospheric ionization are in any way related, the artifical deionization of the air drawn over the plants should have a marked effect on their respiratory activity under the present experimental conditions.

[7] DEMBER, H., Über die ionisierende Wirkung des ultravioletten Sonnenlichts. Physik. Zeitschr. **13**:207–212. 1912.

[8] KAEHLER, K., Luftelektrizität. Leipzig. 1913 (p. 69).

[9] LENARD, P., and RAMSAUER, C., Über die Wirkung Ultravioletten Lichtes auf Gase unter besonderer Berücksichtigung der Vorgänge in der Erdatmosphaere. Metrol. Zeitzchr. **29**:150. 1912.

LENARD, P., Über die Wirkung des Ultravioletten Lichtes auf Gasförmige Körper. Ann. Phys. **1**:486. 1900; **3**:298. 1900.

THOMSON, J. J., Conduction of electricity through gases. Cambridge. 1913 (p. 254).

ELSTER, J., and GEITEL, H., Die Existenz elektrischer Ionen in der Atmosphäre. Jour. Terr. Magnetism and Atmos. Elect. **4**:213. 1899.

STARK, J., Die Elektrizität in Gasen. Leipzig. 1902.

Methods and apparatus

In fig. 1 the apparatus used in this investigation is schematically shown; all of the tubes are of glass with heavy rubber connections. In order to avoid all possible contamination of the air, this was drawn from out-of-doors on the north side of the laboratory building, through a glass tube, and entered the apparatus at E_1. The air was not drawn through any liquid in order to avoid submitting the plants to changes of pressure, and so as not to affect the electrical conditions of the atmosphere. The large bottle (B) contained a 50 per cent aqueous solution of potassium hydroxide; the glass tube was placed so that the air passed immediately over the solution. This bottle was omitted in the experiments of short duration. In order to further remove the carbon dioxide, the air was passed through the bulb tubes (C); the lower portion of the bulbs were filled with 50 per cent potassium hydroxide solution. The tubes were so arranged that they could be shaken from time to time. S represents a glass tube, one inch in diameter, containing coarse soda lime (4 mesh). The air then passed into a Frease electrical thermostat (T). This was kept at 29° in all of the experiments given below. It was, of course, of great importance that the air coming in contact with the plants should also attain the same constant temperature. In order to do this, the air was first passed into a 500 cc. Erlenmeyer flask (F), then through 45 feet of thin-walled glass tubing (G), and finally into the flask R containing the plants. As there was always a small amount of water carried out with the air current, this was condensed and trapped at W. The rate at which the air was allowed to pass through the entire apparatus was controlled by means of the glass stopcock A. It was found that variations in the rate of air from 0.5 to 8 liters per hour caused no difference in the rate of carbon dioxide evolution. P_1 and P_2 represent three-way glass stopcocks, by means of which the course of the air could be changed from one to the other of the Meyer's tubes (M) without interrupting the experiment. The Meyer's tubes were found far more satisfactory for the absorption of carbon dioxide than Pettenkofer tubes or any of the modifications of the latter. Especially was this true in the experiments

running 12–15 hours. The absorption tubes were inserted by making the connection at *L* with heavy rubber tubing; 125 cc.

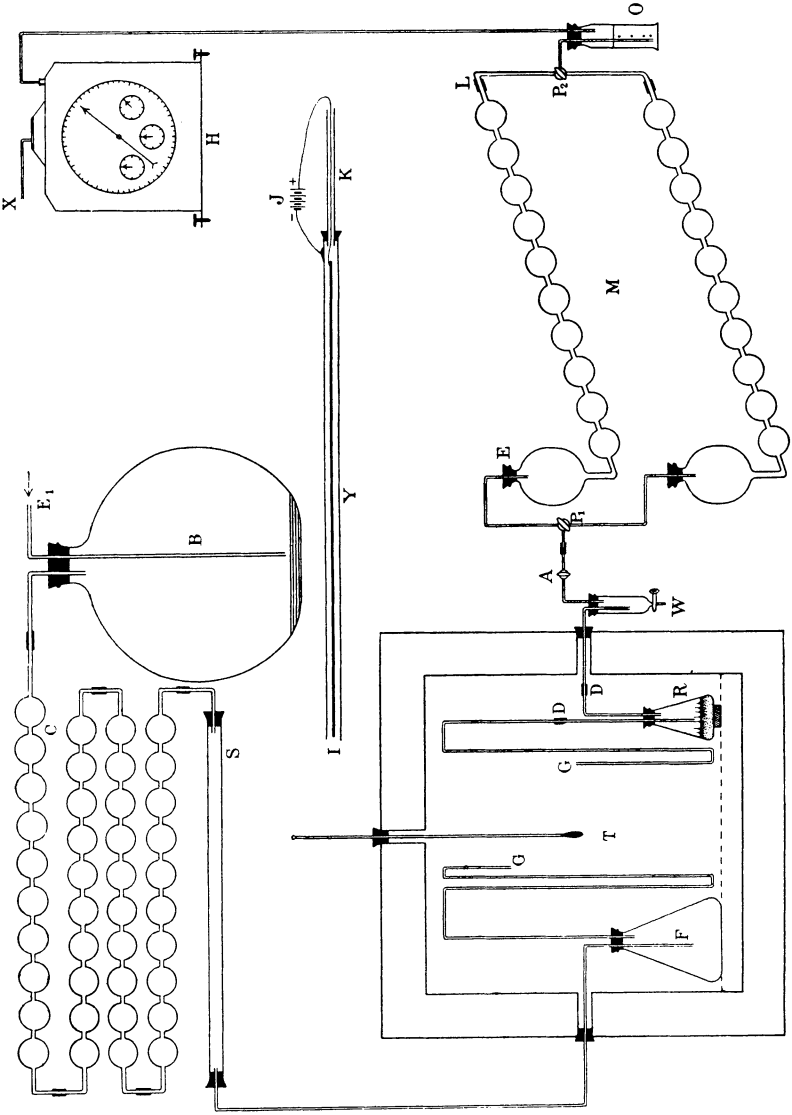

FIG. 1.

of the approximately 0.1 normal barium hydroxide solution was then run into the large bulb, and the connection made at *E* with a

rubber stopper. When the amount of carbon dioxide is large, it is, of course, advisable to use 0.5 normal solution. The tube was then ready for use by turning P_1 and P_2. The error caused by the amount of carbon dioxide of the air in the large bulb was found to be negligible for these experiments. While one tube was in use, the other could be charged. After having drawn the air through one tube for the required length of time, the other was inserted into the system, and the barium hydroxide solution from the first plus the precipitated barium carbonate poured into a narrow bottle, well stoppered, and the barium carbonate allowed to settle for 24 hours; 25cc. of the clear supernatant solution was then titrated with 0.1 normal hydrochloric acid. From the difference between the amount of acid required for the used barium hydroxide solution and the original solution, the amount of carbon dioxide evolved can be very simply calculated. In the figure, *O* is a small wash bottle containing barium hydroxide solution, to detect any escaping carbon dioxide beyond the Meyer's tubes; this was never found to take place. The rate of air flow was measured by means of the gas meter *H*. At *X* connection was made with a Palladin pressure regulator, and this was attached to an electrically driven suction pump.

The nature of the plant material used for these experiments was found to be of greatest importance. Briefly, it is necessary that the organisms be actively respiring, and that the gaseous exchange with the atmosphere be not too difficult. For instance, potato tubers evolve carbon dioxide so slowly that even with a large quantity the differences between day and night are exceedingly slight. There must also be a sufficient supply of carbohydrate food material, for it was found that as soon as the carbohydrates were exhausted, the nature of the carbon dioxide evolution changed greatly.[10] The difficulty with wheat seedlings is, of course, that the relatively rapid rise and fall of the rate of carbon dioxide evolution makes a comparison between day and night

[10] Compare Deleano, N. T., Untersuchungen über den Atmungsstoffwechsel abgeschnittener Blätter. Jahrb. Wiss. Bot. **51**:541–593. 1912. He found that only after the exhaustion of the carbohydrates was there any evidence of protoplasmic disturbance.

rather difficult. I believe, however, that for the present purpose these experiments will serve as the best illustration.

Before starting an experiment, the wheat grains were always sterilized: *R*, an Erlenmeyer flask (of 100cc. for the experiments with 70 seedlings, 1000cc. when 200 seedlings were used) was provided with a rubber stopper and glass tubing which could be detached at *D*. The bottom of the flask was covered with about an inch of glass wool, and the flask and tubing were then sterilized in the autoclave. The wheat grains were placed in a small cheesecloth sack, immersed for three minutes in a concentrated aqueous solution of chloroform, and shaken to free the seeds from adhering air bubbles. As much as possible of the chloroform solution was removed, and the contents quickly emptied into the sterile flask. Dry, carefully filtered air was then drawn through the flask for at least 24 hours until the seeds were perfectly air dry, so that no trace of chloroform could remain in the flask. Sterile water was then added through one of the tubes; these were then connected at *D*. Material treated in this way very rarely developed any growth of fungus during the course of the experiment, nor did it show any differences in growth as compared with untreated seeds. It is highly improbable, therefore, that the seed coats were penetrated by the chloroform solution. It was found that the wheat could also be sterilized by means of ultra-violet light. This is an exceedingly convenient method, but as it was found that the subsequent growth of the seedlings was somewhat affected, the method was not used for these experiments.

The deionizing apparatus used consisted of a brass tube (*Y*) five feet long and one inch in diameter. Into this was concentrically placed an iron rod, the same length and one-quarter inch in diameter, and held by fiber supports. The tube and rod were attached to the opposite poles of a series of batteries of 50 volts and 800 amperes. To one end of the brass tube was connected a glass tube containing cotton, to act as a filter. The deionizing apparatus was connected at *I* with *E*.

Blank experiments were, of course, always run in order to test the apparatus. In experiments 1, 2, 4, and 5 it will be noted that the night periods are longer than the day periods. It is conceivable

that drawing air through the barium hydroxide solution would evaporate some water, thus make the solution more concentrated, and hence give lower values for the longer periods. The following blank experiment eliminates this possibility.

25 cc. original $Ba(OH)_2$ solution	= 27.19 cc.	0.1	NHCl
25 cc. after 3.5 hours	= 27.05 cc.	"	"
25 cc. after 16 hours	= 26.99 cc.	"	"

That differences in atmospheric pressure might account for the daily variation in carbon dioxide evolution also suggested itself. The exceedingly slight variations of pressure at Tucson bear no possible similarity to the values of respiration.

Experimental results

The following is a brief account of a few typical experiments carried out during the winter of 1913–1914. The first column in the tables gives the number of the carbon dioxide determination; the second, the time of day during which it ran; the third, the number of hours; the fourth, the rate per hour at which the air was drawn over the plants in liters; the fifth, the rate of carbon dioxide evolved per hour, expressed in milligrams. In the sixth column the weather is roughly indicated: *A* stands for a perfectly cloudless day; *B*, a few scattered cumulus clouds; *C*, more clouds than *B*, usually thin cirrus; *O*, overcast; and *R*, rain.

The curves are plotted with the rate of carbon dioxide evolution per hour in mg. on the ordinates, the successive determinations on the abscissas; the broken lines indicate the day rates, the solid lines the night rates.

(1) The first experiments (p. 374) were made with small onion bulbs (Australian brown) 0.75–1 inch in diameter. In order to insure ease of gaseous exchange in the onions, the dry outer layers were removed. Previous experiments showed that this operation resulted in but a very slight traumatic effect. After 24 hours, 35 of these small onions were placed in flask *R*. To prevent drying out, the air was drawn over water contained in a bottle inserted between the tubes *G* and the flask *R*. The experiment ran from January 21 to February 2. The results are given in table I and fig. 2. Here it can be seen that the differences in carbon dioxide

TABLE I

No.	Time	Hours	Air per hour	mg. CO_2 per hour	Weather
1	10:30 A.M.– 5:30 P.M.	7.00	6.86	4.47	A–B
2	5:30 P.M.– 8:30 A.M.	15.00	6.14	3.45	A
3	8:30 A.M.– 5:30 P.M.	9.00	5.78	3.21	C
4	5:30 P.M.– 8:30 A.M.	15.00	5.93	2.57	O
5	8:30 A.M.– 5:00 P.M.	8.50	5.65	2.42	O
6	5:00 P.M.–10:00 A.M.	17.00	5.76	2.13	C
7	10:00 A.M.– 3:15 P.M.	5.25	5.52	2.20	O
8	3:15 P.M.–10:15 A.M.	19.00	5.42	1.98	O
9	10:15 A.M.– 6:15 P.M.	8.00	5.12	1.89	C
10	6:15 P.M.– 9:00 A.M.	14.75	4.95	1.76	O
11	9:00 A.M.– 4:45 P.M.	7.75	4.91	2.11	O
12	4:45 P.M.– 8:30 A.M.	15.75	4.95	1.96	O
13	8:30 A.M.– 5:00 P.M.	8.50	4.82	1.81	O
14	5:00 P.M.– 8:15 A.M.	15.25	4.79	1.67	R
15	8:15 A.M.– 5:15 P.M.	9.00	4.89	1.61	C–A
16	5:15 P.M.– 8:45 A.M.	15.25	4.65	1.58	A
17	8:45 A.M.– 5:30 P.M.	8.75	4.46	1.56	A
18	5:30 P.M.– 8:45 A.M.	15.25	4.39	1.50	A
19	8:45 A.M.– 5:30 P.M.	8.75	4.23	1.67	A
20	5:30 P.M.– 8:30 A.M.	15.00	3.93	1.63	A
21	8:30 A.M.– 5:30 P.M.	9.00	6.22	1.56	A
22	5:30 P.M.– 9:00 A.M.	15.50	6.71	1.45	B
23	9:00 A.M.– 6:00 P.M.	9.00	7.00	1.43	B
24	6:00 P.M.–10:15 A.M.	16.25	6.89	1.56	A

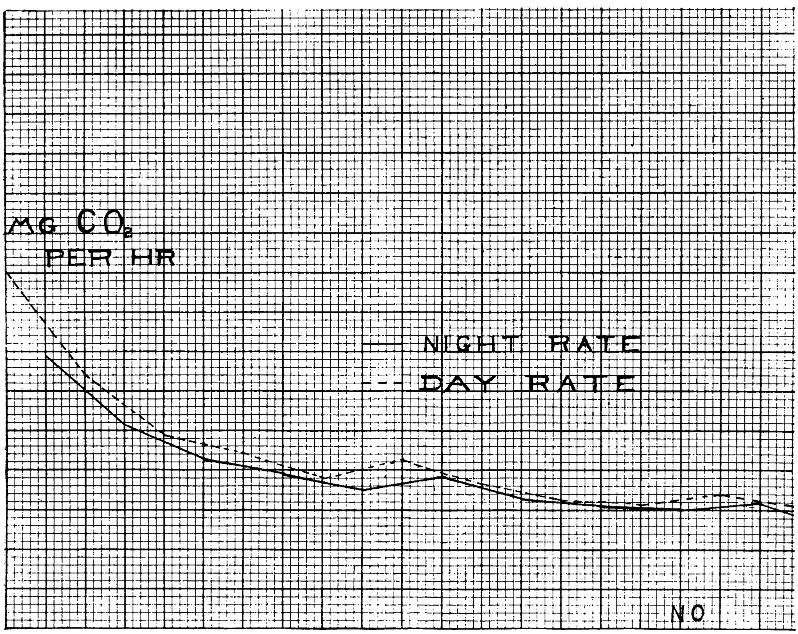

FIG. 2.

production between day and night grow less as the food material is used up, and as the gaseous exchange becomes more difficult, because the shriveled outer layer forms a protecting coat. The amount of carbon dioxide evolved from onions in which the outer layer is dry and contains little food material is very small. $\frac{\text{Day rate}}{\text{Night rate}}=1.15$.

(2) In the next experiment (p. 376) 75 wheat seedlings were used. This was started after the seedlings were 24 hours old, and ran from February 11 to 24. The results are given in table II and fig. 3. $\frac{\text{Day rate}}{\text{Night rate}}=1.042$.

(3) In the experiment tabulated on p. 377, 70 wheat seedlings were used, which ran from April 29 to May 9. Several of the seeds were infected with fungus, wherefore the experiment was not run longer. The results are given in table III and fig. 4. $\frac{\text{Day rate}}{\text{Night rate}}=1.091$.

(4) The deionizing apparatus was used in the next experiment (p. 378), and 70 wheat seedlings were used. The experiment ran from April 14 to April 25. Unfortunately, however, on the night of April 17–18 the pump was out of order, and the determination for that period is not reliable. The results are given in table IV and fig. 5.

(5) Here also (p. 379) the deionizing apparatus was used, with 70 wheat seedlings in the flask. The experiment ran from March 13 to 20. The results are given in table V and fig. 6. $\frac{\text{Day rate}}{\text{Night rate}}=1.010$.

(6) The deionizing apparatus was used here (p. 380), with 70 wheat seedlings. The experiment ran from May 11 to 22. The results are given in table VI and fig. 7. $\frac{\text{Day rate}}{\text{Night rate}}=1.015$.

(7) In this experiment (p. 381) the carbon dioxide was determined for three hour periods, and 200 wheat seedlings were used. The experiment ran from May 25 to 27, and the deionizing apparatus was not used. The results are given in table VII and fig. 8. At this time of the year the night time must be considered as falling within

TABLE II

No.	Time	Hours	Air per hour	mg. CO_2 per hour	Weather
1	5:45 P.M.– 8:45 A.M.	15.00	2.27	2.68	A
2	8:45 A.M.– 5:30 P.M.	8.75	3.09	4.54	A
3	5:30 P.M.– 8:15 A.M.	14.75	4.41	5.59	B
4	8:15 A.M.– 6:00 P.M.	9.75	4.21	6.98	B
5	6:00 P.M.– 9:00 A.M.	15.00	4.40	8.10	B
6	9:00 A.M.– 6:00 P.M.	9.00	4.22	9.20	B–C
7	6:00 P.M.– 9:00 A.M.	15.00	4.13	9.28	C
8	9:00 A.M.– 6:00 P.M.	9.00	3.89	9.50	B–C
9	6:00 P.M.– 9:00 A.M.	15.00	4.00	8.84	O
10	9:00 A.M.– 7:00 P.M.	10.00	2.80	8.67	C
11	7:00 P.M.– 9:30 A.M.	14.50	2.83	8.12	R
12	9:30 A.M.– 7:30 P.M.	10.00	4.90	8.30	R
13	7:30 P.M.– 9:30 A.M.	14.00	5.21	8.16	R
14	9:30 A.M.– 7:30 P.M.	10.00	3.90	8.45	O
15	7:30 P.M.– 9:30 A.M.	14.00	4.00	8.20	R
16	9:30 A.M.– 8:30 P.M.	11.00	3.91	7.64	B
17	8:30 P.M.–10:00 A.M.	13.50	4.08	6.93	B
18	10:00 A.M.– 8:00 P.M.	10.00	3.80	6.60	B
19	8:00 P.M.–10:00 A.M.	14.00	4.14	6.00	B
20	10:00 A.M.– 7:15 P.M.	9.25	4.22	5.70	C
21	7:15 P.M.– 9:15 A.M.	14.00	4.07	5.10	R
22	9:15 A.M.– 6:15 P.M.	9.00	4.00	4.78	B
23	6:15 P.M.– 9:15 A.M.	15.00	4.07	4.20	B
24	9:15 A.M.– 6:00 P.M.	8.75	4.00	3.88	O

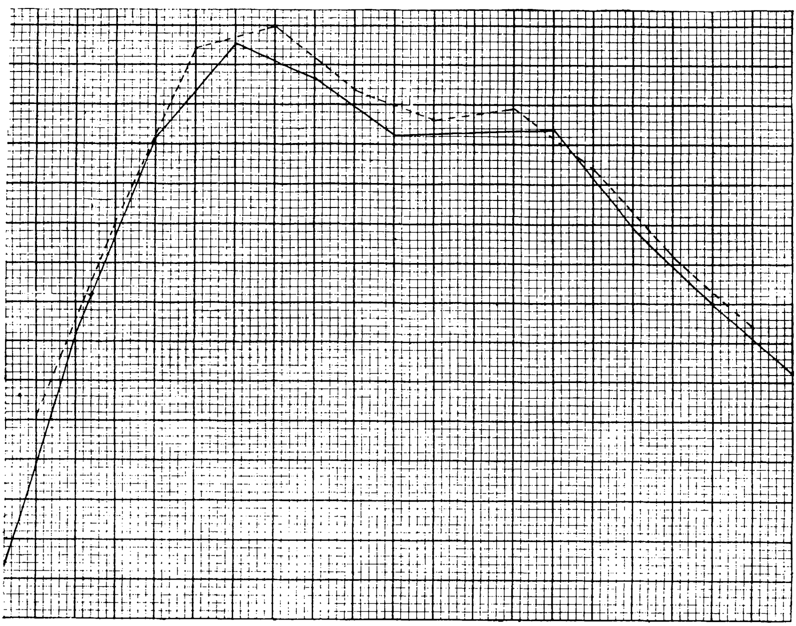

FIG. 3.

TABLE III

No.	Time	Hours	Air per hour	mg. CO_2 per hour	Weather
1	8:30 P.M.– 8:15 A.M.	11.75	0.76	0.36	B–C
2	8:15 A.M.– 7:45 P.M.	11.50	0.69	0.90	B
3	7:45 P.M.– 8:15 A.M.	12.50	0.96	1.19	B
4	8:15 A.M.– 7:45 P.M.	11.50	1.74	1.76	B–C
5	7:45 P.M.– 8:30 A.M.	12.75	1.88	2.13	B
6	8:30 A.M.– 8:15 P.M.	11.75	1.88	2.62	B–C
7	8:15 P.M.–11:00 A.M.	14.75	2.03	2.97	B
8	11:00 A.M.– 8:45 P.M.	9.75	1.95	3.26	B
9	8:45 P.M.– 8:15 A.M.	11.50	1.83	3.34	A
10	8:15 A.M.– 8:15 P.M.	12.00	1.67	3.46	B
11	8:15 P.M.– 8:30 A.M.	12.25	1.63	3.77	B
12	8:30 A.M.– 8:00 P.M.	11.50	1.83	4.01	O
13	8:00 P.M.– 7:45 A.M.	11.75	1.96	4.16	B
14	7:45 A.M.– 8:00 P.M.	12.25	1.55	4.27	B–A
15	8:00 P.M.– 8:30 A.M.	12.50	1.76	4.40	A
16	8:30 A.M.– 8:00 P.M.	11.50	1.83	4.69	B
17	8:00 P.M.– 8:45 A.M.	12.75	2.12	4.86	B–C
18	8:45 A.M.– 8:00 P.M.	11.75	2.13	5.04	O
19	8:00 P.M.– 8:15 A.M.	12.25	2.28	4.95	C
20	8:15 A.M.– 5:00 P.M.	8.75	2.17	5.06	B

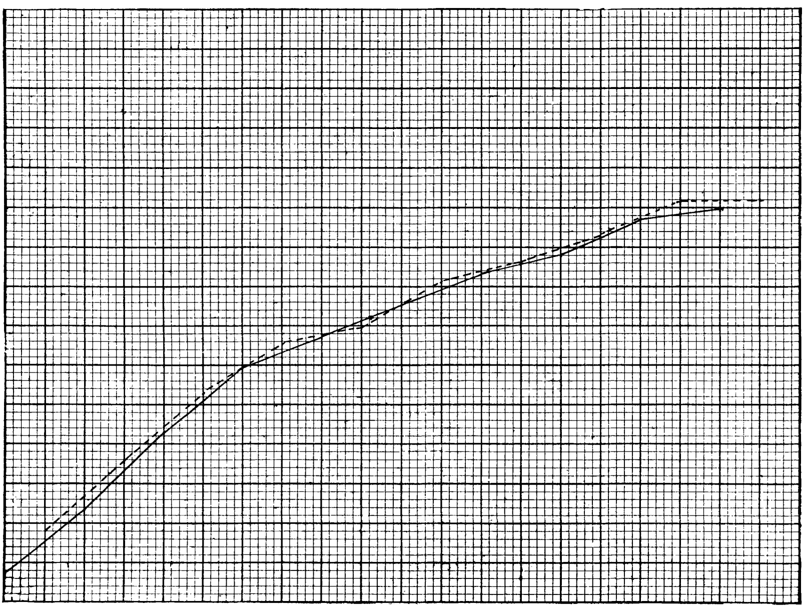

FIG. 4.

TABLE IV

No.	Time	Hours	Air per hour	mg. CO_2 per hour	Weather
1	4:00 P.M.– 8:30 A.M.	16.50	1.70	0.35	A
2	8:30 A.M.– 5:30 P.M.	9.00	1.33	1.34	A
3	5:30 P.M.– 8:45 A.M.	15.25	1.44	2.73	A
4	8:45 A.M.– 5:30 P.M.	8.75	1.37	3.74	A
5	5:30 P.M.– 9:00 A.M.	15.50	1.37	4.64	A
6	9:00 A.M.– 5:15 P.M.	8.25	1.45	5.80	A
7	5:15 P.M.– 9:30 A.M.	16.25	1.05	....	A
8	9:30 A.M.– 5:45 P.M.	8.25	1.21	5.99	A
9	5:45 P.M.– 8:00 A.M.	14.25	1.33	7.41	A
10	8:00 A.M.– 6:15 P.M.	10.25	1.17	6.91	A
11	6:15 P.M.– 8:30 A.M.	14.25	1.26	6.60	A
12	8:30 A.M.– 5:30 P.M.	9.00	1.12	6.25	B
13	5:30 P.M.– 8:45 A.M.	15.25	1.18	6.14	O
14	8:45 A.M.– 6:30 P.M.	9.75	1.13	6.18	O
15	6:30 P.M.– 8:30 A.M.	14.00	1.28	6.12	B
16	8:30 A.M.– 6:15 P.M.	9.75	1.13	6.35	B
17	6:15 P.M.– 8:30 A.M.	14.25	1.19	6.23	B–C
18	8:30 A.M.– 5:00 P.M.	8.50	1.06	6.18	C
19	5:00 P.M.– 8:15 A.M.	15.25	1.11	5.74	B–A
20	8:15 A.M.– 5:15 P.M.	9.00	1.00	4.82	A
21	5:15 P.M.– 8:00 A.M.	14.75	0.68	4.67	A
22	8:00 A.M.– 2:45 P.M.	6.75	0.59	4.55	A

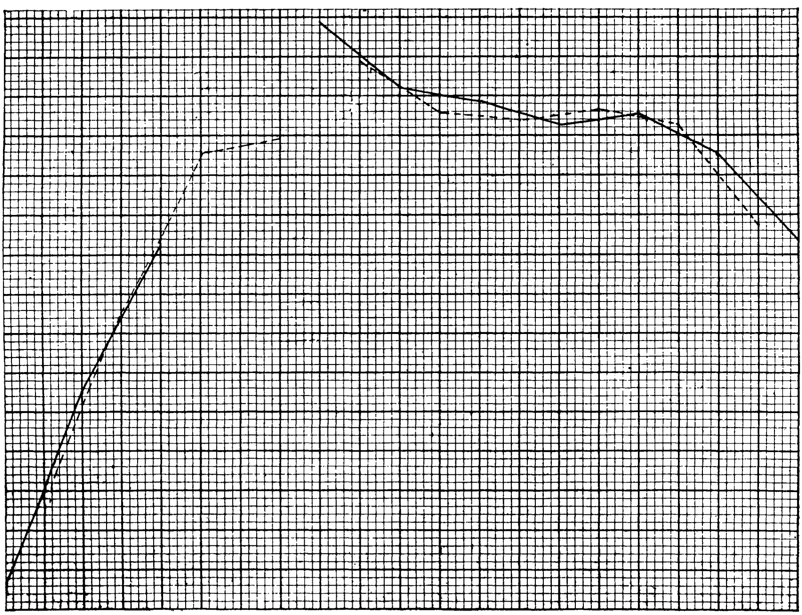

FIG. 5.

TABLE V

No.	Time	Hours	Air per hour	mg. CO_2 per hour	Weather
1	5:00 P.M.–8:30 A.M.	15.50	3.42	8.14	A
2	8:30 A.M.–6:00 P.M.	9.50	3.90	10.95	A
3	6:00 P.M.–8:30 A.M.	14.50	3.93	12.65	O
4	8:30 A.M.–6:15 P.M.	9.75	4.00	14.81	O
5	6:15 P.M.–8:30 A.M.	14.25	3.93	15.88	A
6	8:30 A.M.–7:30 P.M.	11.00	4.19	16.01	B
7	7:30 P.M.–8:30 A.M.	13.00	4.08	16.45	A
8	8:30 A.M.–5:30 P.M.	9.00	3.11	16.07	B–C
9	5:30 P.M.–8:30 A.M.	15.00	2.93	15.55	O
10	8:30 A.M.–7:30 P.M.	11.00	2.82	15.27	B–C
11	7:30 P.M.–9:00 A.M.	13.50	2.89	14.28	O
12	9:00 A.M.–5:30 P.M.	8.50	3.76	13.14	R
13	5:30 P.M.–8:30 A.M.	15.00	3.87	12.10	B
14	8:30 A.M.–5:30 P.M.	9.00	3.77	11.83	O

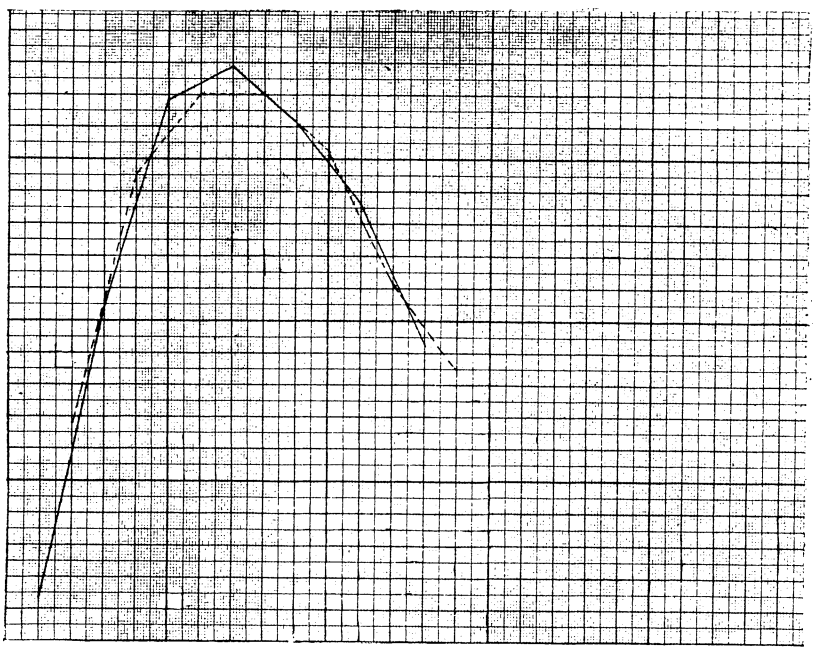

FIG. 6.

TABLE VI

No.	Time	Hours	Air per hour	mg. CO_2 per hour	Weather
1	9:15 P.M.–8:45 A.M.	11.50	1.65	0.34	C
2	8:45 A.M.–7:00 P.M.	10.25	1.94	0.96	A
3	7:00 P.M.–8:45 A.M.	13.75	1.74	2.03	B
4	8:45 A.M.–8:00 P.M.	11.25	1.91	3.01	O
5	8:00 P.M.–8:15 A.M.	12.25	1.96	3.79	O
6	8:15 A.M.–8:00 P.M.	11.75	1.96	4.56	B
7	8:00 P.M.–8:00 A.M.	12.00	1.83	5.09	A
8	8:00 A.M.–8:45 P.M.	12.75	1.80	5.92	B
9	8:45 P.M.–8:00 A.M.	11.25	1.88	6.20	A
10	8:00 A.M.–8:00 P.M.	12.00	1.93	6.14	O
11	8:00 P.M.–8:00 A.M.	12.00	1.83	6.23	B–A
12	8:00 A.M.–8:00 P.M.	12.00	1.83	6.27	B–A
13	8:00 P.M.–8:15 A.M.	12.25	2.04	5.86	A
14	8:15 A.M.–8:00 P.M.	11.75	1.96	6.11	B
15	8:00 P.M.–8:00 A.M.	12.00	1.93	5.96	A
16	8:00 A.M.–8:45 P.M.	12.75	1.96	5.46	A
17	8:45 P.M.–8:15 A.M.	11.50	2.00	6.65	A
18	8:15 A.M.–8:45 P.M.	12.50	2.18	6.89	B
19	8:45 P.M.–8:30 A.M.	11.75	2.05	7.05	A
20	8:30 A.M.–8:45 P.M.	12.25	2.04	7.31	A
21	8:45 P.M.–8:00 A.M.	11.25	3.70	6.98	B
22	8:00 A.M.–4:15 P.M.	8.25	2.01	5.37	C

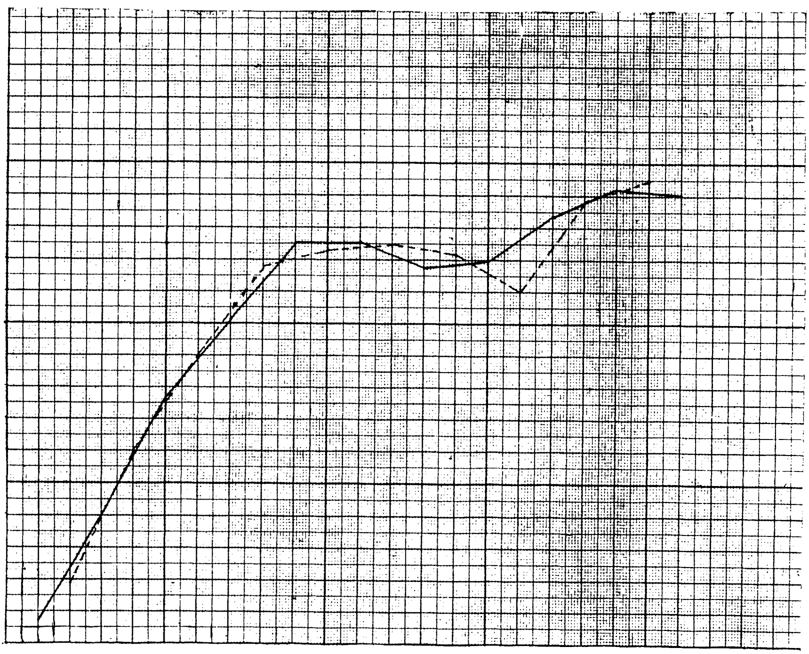

FIG. 7.

TABLE VII

No.	Time	Hours	Air per hour	mg. CO_2 per hour	Weather
1	12:00 N. – 3:00 A.M.	3	2.00	10.93	A
2	3:00 A.M.– 6:00 A.M.	3	2.33	10.93	A–B
3	6:00 A.M.– 9:00 A.M.	3	2.33	11.88	B
4	9:00 A.M.–12:00 M.	3	2.33	12.47	B
5	12:00 M. – 3:00 P.M.	3	2.00	12.16	B
6	3:00 P.M.– 6:00 P.M.	3	2.33	12.32	B
7	6:00 P.M.– 9:00 P.M.	3	2.33	13.52	B
8	9:00 P.M.–12:00 N.	3	2.33	13.31	A
9	12:00 N. – 3:00 A.M.	3	2.33	14.41	A
10	3:00 A.M.– 6:00 A.M.	3	2.33	14.20	A
11	6:00 A.M.– 9:00 A.M.	3	2.66	15.62	A
12	9:00 A.M.–12:00 M.	3	2.00	15.39	B
13	12:00 M. – 3:00 P.M.	3	2.33	16.01	A
14	3:00 P.M.– 6:00 P.M.	3	2.00	15.91	B
15	6:00 P.M.– 9:00 P.M.	3	2.33	17.11	A
16	9:00 P.M.–12:00 N.	3	2.33	17.22	A
17	12:00 N. – 3:00 A.M.	3	2.00	17.77	A
18	3:00 A.M.– 6:00 A.M.	3	2.00	17.16	A
19	6:00 A.M.– 9:00 A.M.	3	1.67	17.87	A
20	9:00 A.M.–12:00 M.	3	1.67	18.62	A
21	12:00 M. – 3:00 P.M.	3	1.67	19.10	A
22	3:00 P.M.– 6:00 P.M.	3	2.00	18.81	A
23	6:00 P.M.– 9:00 P.M.	3	1.33	19.36	A
24	9:00 P.M.–12:00 N.	3	1.67	18.74	A

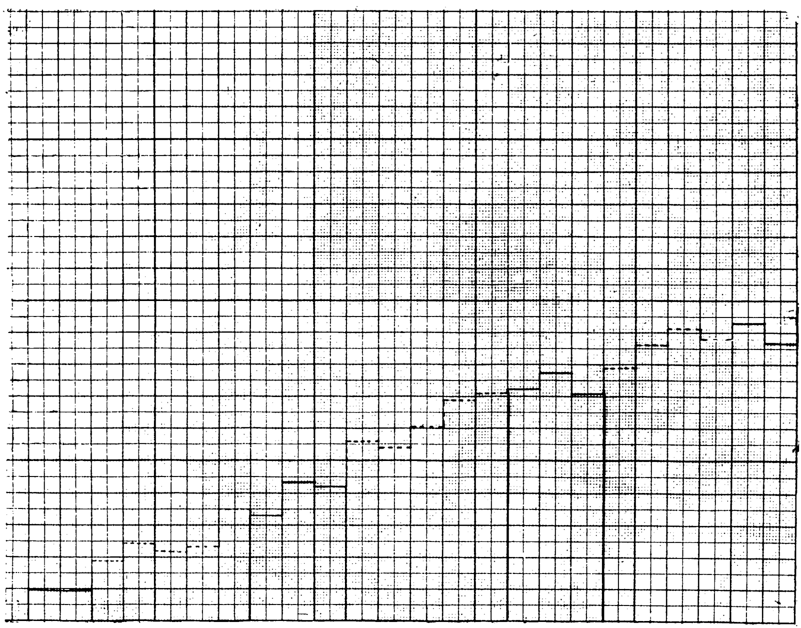

FIG. 8.

TABLE VIII

No.	Time	Hours	Air per hour	mg. CO_2 per hour	Weather
1	6:00 P.M.– 9:00 P.M.	3	2.67	10.12	B
2	9:00 P.M.–12:00 N.	3	2.00	10.40	B
3	12:00 N. – 3:00 A.M.	3	2.00	11.72	B
4	3:00 A.M.– 6:00 A.M.	3	2.33	12.61	B
5	6:00 A.M.– 9:00 A.M.	3	2.00	13.71	C
6	9:00 A.M.–12:00 M.	3	2.00	14.96	C
7	12:00 M. – 3:00 P.M.	3	2.00	15.72	C
8	3:00 P.M.– 6:00 P.M.	3	2.00	17.00	C
9	6:00 P.M.– 9:00 P.M.	3	2.33	17.30	C
10	9:00 P.M.–12:00 N.	3	2.33	17.60	C
11	12:00 N. – 3:00 A.M.	3	2.33	18.42	B
12	3:00 A.M.– 6:00 A.M.	3	2.33	19.36	B–C
13	6:00 A.M.– 9:00 A.M.	3	2.33	19.68	C
14	9:00 A.M.–12:00 M.	3	2.00	19.91	C
15	12:00 M. – 3:00 P.M.	3	2.33	21.08	R
16	3:00 P.M.– 6:00 P.M.	3	2.00	21.50	R
17	6:00 P.M.– 9:00 P.M.	3	2.00	21.91	R
18	9:00 P.M.–12:00 N.	3	2.33	22.45	B
19	12:00 N. – 3:00 A.M.	3	2.00	23.83	A
20	3:00 A.M.– 6:00 A.M.	3	2.00	25.12	A
21	6:00 A.M.– 9:00 A.M.	3	2.33	25.52	B
22	9:00 A.M.–12:00 M.	3	2.00	26.77	C

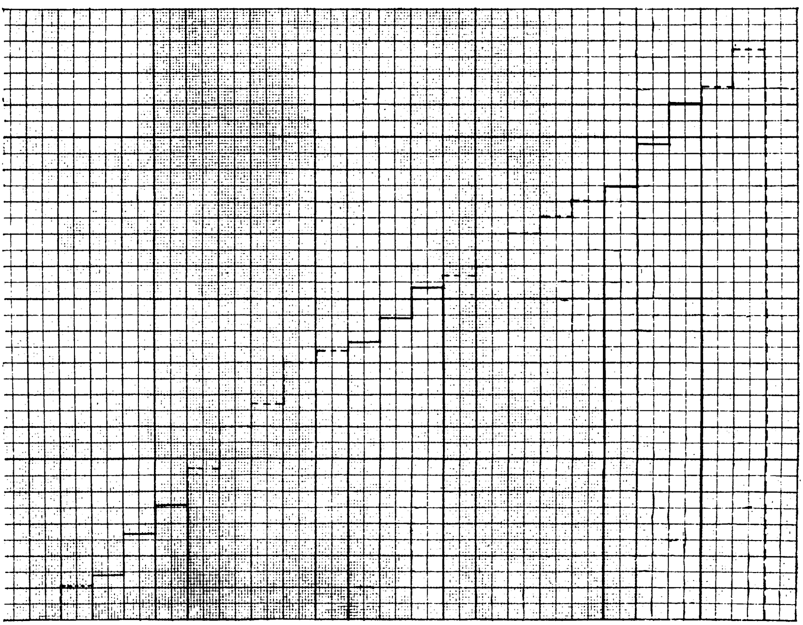

FIG. 9.

the periods between 9 P.M. and 6 A.M. It is impossible to derive an accurate $\frac{\text{day rate}}{\text{night rate}}$ ratio from so short an experiment. An arrangement for automatically taking out the used and putting

TABLE IX

No.	Time	Hours	Air per hour	mg. CO_2 per hour	Weather
1	8:00 P.M.–6:00 A.M.	10.00	4.00	3.36	A
2	6:00 A.M.–8:00 P.M.	14.00	3.70	3.59	A
3	8:00 P.M.–6:00 A.M.	10.00	5.10	3.59	A
4	9:15 A.M.–8:00 P.M.	10.75	2.23	4.18	A
5	8:00 P.M.–6:00 A.M.	10.00	3.30	4.18	A
6	6:00 A.M.–8:00 P.M.	14.00	2.85	4.47	B

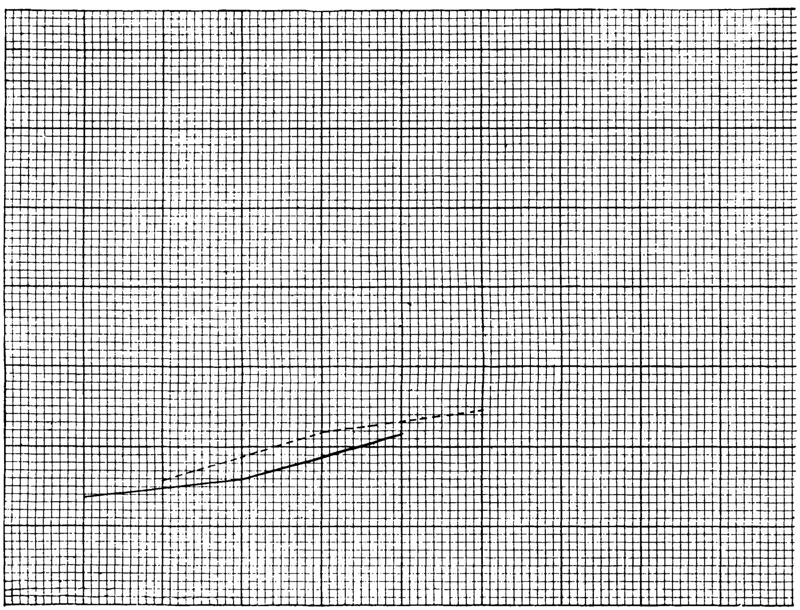

FIG. 10.

in the new Meyer's tubes will materially reduce the personal labor involved in the observations. The striking feature of the curve is the great irregularity of the single observations. Obviously it will be necessary to make measurements of the atmospheric conductivity simultaneously with those of carbon dioxide evolution in order to gain more light on these observations.

(8) Inserting the deionizing tube (p. 382), the other conditions were the same as in 7. The experiment ran from May 28 to 31. The results are given in table VIII and fig. 9. Here the rate shows a very much more regular increase.

(9) In order to determine whether the daily variation in carbon dioxide evolution was restricted to plants or whether it took place also in animals, an experiment (p. 383) was made with ten beetles,[11] placed in flask *R* on fine asbestos fiber soaked in water. Twice during the course of the experiment 2 cc. of water were run onto the asbestos. To all appearances, the beetles behaved perfectly normally during this time. The experiment ran from June 3 to 6. The results are given in table IX and fig. 10. $\frac{\text{Day rate}}{\text{Night rate}} = 1.099$.

Discussion

Although it is difficult to derive an exact $\frac{\text{day rate}}{\text{night rate}}$ ratio with material in which the respiratory activity is rapidly rising or falling, the following in a sense summarizes those of the foregoing experiments which ran for a longer time:

Material	$\frac{\text{Day rate}}{\text{Night rate}}$ normal air	$\frac{\text{Day rate}}{\text{Night rate}}$ deionized air
Onion	1.150	.....
Wheat	1.042	1.010
Wheat	1.091	1.014
Beetles	1.099	.....

There is at present no satisfactory explanation of these facts. The phenomenon of atmospheric ionization is undoubtedly exceedingly complicated, and perhaps at first glance far removed from our present conceptions of climatological factors of physiological importance. However, in view of the fact that ionization of the atmosphere is indicative of important chemical changes in the gases of the atmosphere, a physiological response to these changes is at least to be expected. These chemical changes, no doubt, are of such a nature as to affect the valency or activity of the atmospheric gases, in this case more especially the oxygen.

[11] The material (*Leptinotarsa 10-lineata*) was kindly loaned by Mr. JOHN SINCLAIR, in charge at Tucson of the investigations of Professor W. L. TOWER.

For example, the formation of ozone from molecular oxygen prerequires at least a partial dissociation of the oxygen molecule. It is interesting to note that in Vienna a relation of atmospheric ionization to the amount of ozone was established, the latter increasing with the former.[12] From the work of J. J. THOMSON[13] we know that the chemical effects produced by light are due to the emission of corpuscles from some of the atoms of the illuminated substance. Valency, under this conception, depends upon the relative ability of the atoms to eject or attract corpuscles. Now, it is of especial importance to note that BACH,[14] in elaborating the investigations and theories of MORITZ TRAUBE with especial reference to biological oxidative processes, comes to the conclusion that it is the partially dissociated oxygen (—O—O—) which combines with the oxidizable substance. Furthermore, C. ENGLER,[15] who with his co-workers has done a great deal to extend our knowledge of autoxidation, lays great stress upon the idea that for autoxidative processes the dissociation or liberation of free valencies in the oxygen molecule is necessary, and in this way he explains the accelerating influence of light and heat on oxidative processes. This very brief statement shows, I believe, that the air may possess higher "oxidative power" during the hours of illumination than during darkness.

In the foregoing pages the term respiratory activity has been used in a very general sense, and with special reference to aerobic respiration. There is, of course, little reason for supposing that the ionization of the atmosphere in any way affects the first stages in the katabolic processes, the breaking down or splitting of complex chemical substances. It is probably only in the oxidative processes that the action of the air plays a rôle. In what stages in the series of changes involved in this highly complicated process oxygen

[12] KAEHLER, KARL, Luftelektrizität. p. 56.

[13] THOMSON, J. J., The conduction of electricity through gases. Cambridge. 1913 (p. 290).

[14] BACH, M., Du rôle des peroxydes dans les phénomènes d'oxydation lente. Compt. Rend. Acad. Sci. **124**:951–954. 1897.

[15] ENGLER, C., and WEISBERG, J., Kritische Studien über die Vorgänge der Autoxydation. Braunschweig. 1904.

KASTLE, J. H., The oxidases and other oxygen-catalysts concerned in biological oxidations. U.S. Hygienic Lab. Bull. **59**:9–30. 1910.

enters, is as yet not definitely established; nor can the formation of carbon dioxide be attributed entirely to the oxidative action of the oxygen. We know, however, that the total rate of respiration is greatly influenced by the accumulation or removal of the end products of the first stages in the series. Even assuming, then, that the only function of the oxygen is the removal of these end products, as is maintained by many physiologists, the more rapid oxidation of these substances would result in an increased total rate, and hence increased total amount of carbon dioxide evolved. This higher rate of oxidation, and consequent greater carbon dioxide evolution during the hours of sunlight, could be accounted for by the increased "oxidative power" of the air during this time. That no increased respiratory activity can be obtained with the use of artificial sources of light (except possibly the quartz mercury vapor lamps) is but natural, for light from these sources has no influence on the atmosphere.

The factors influencing atmospheric ionization should be briefly mentioned. Water vapor and high relative humidity have been found to decrease greatly the values; observations made at high altitudes usually show higher values than those made at about sea level. It is to be expected, therefore, that the respiratory activity in the arid and high regions, as, for instance, at Tucson, would be higher and show greater day and night variations than in a moist climate and at sea level.

Finally, it should be stated that the day and night variations as reported in this notice are not of great magnitude, and can be detected only by careful and rather prolonged experiments. The phenomenon is none the less important, however, when considered in its broader physiological bearing. The development of this hypothesis will naturally require many more experiments. Work is now in progress with still finer temperature regulations and on a larger variety of plants and animals. It is my intention to make simultaneous atmospheric conductivity measurements, and to study the effect of air artificially ionized by means of Roentgen rays or radium.

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